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Assessing the Health and Safety Aspects of Reboiler Maintenance Activities

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Abstract

Maintenance on equipment at an oil and gas facility is an everyday occurrence in Alberta, Canada. Due to their inherent hazards, especially from explosion, fire and chemicals, these facilities (refineries and upgraders) are tightly regulated places in which to work. In these plants, hazards can come in many different shapes and forms; all of which must be mitigated to ensure the safety of both the equipment and the workers. Examples of such hazards include hydrogen sulphide (H_2S), naturally occurring radioactive material (NORM), ergonomics and noise.

The intent of this survey was to determine if there were any gaps in Client A's and Company B's procedures that result in endangering the workforce. The effectiveness of the mitigations in place for H_2S, NORM, ergonomics and noise were all surveyed via gas and vapour survey, NORM Survey, ergonomics survey and noise survey.

The findings suggest that the maintenance company (Company B) has deficiencies in their procedures and that the Client (Client A) has procedures to keep the exposure levels below Alberta Occupational Exposure Limits but still warrants further investigation.

Keywords: maintenance, reboiler, shutdown

Dedication

I wish to thank my family for their support and understanding while completing this program.

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1. Introduction

The main job of an Upgrader is to upgrade the bitumen that comes from the oil sands into synthetic crude oil so it can be handled by a refinery. The main job of a refinery is to split crude oil into its many parts, which are then reprocessed into useful products. The type, number, and size of the process units required at a particular plant depends on a variety of factors including the type of crude oil and products required. The interconnected units which make up these plants are a maze of tanks, furnaces, distillation towers, reactors, heat exchangers, pumps, pipes, fittings and valve; each of which has their own set of hazards.

The principal exposures to hazardous substances in these plants occur during shutdown or maintenance work, as these are a deviation from routine operations. If a plant is able to, they can often perform running maintenance, which is working on the equipment within the units without actually shutting down the plant. The planning involved in this is intense as the hazards increase with the plant still running.

The industrial hygienist plays a large role in this planning as many of the hazards will help determine if the running maintenance on the plant can be performed without exposing the workforce to unnecessary hazards.

The Upgrader that this study took place at (Client A) has 2 Sulphur Recovery Units. These units process the H_2S (hydrogen sulphide) rich gas recovered from the process. The sulphur that is recovered from this process is then transported by rail and tanker to other facilities to be used.

Each of these trains utilizes a reboiler, which is a heat exchanger used to provide heat to the water stripper. A reboiler consists of a shell side and tube side which uses the process of heat exchange to reach the desired temperature needed. The tubes in one of the reboilers on site were not working efficiently and Client A wanted to isolate the equipment and perform running maintenance to avoid an entire plant shutdown. To complete this work, they have employed a maintenance company (Company B) to isolate and repair the reboiler.

The task involved blinding for isolation and entry, disassembling components (removing the spools and channel head) and pulling the bundle from the tube so it could be sent off site for inspection and cleaning.

1.1. Reboilers

Reboiler maintenance is a common task within the petro-chemical industry. The governing body (ABSA, Alberta Boilers Safety Association in this province) require that the equipment in plants be registered, inspected and maintained up to code.

Reboiler design consists of 4 steps: process specification, piping arrangement, thermal design and hydraulic balance (Chen, 2001)[1]. A good reboiler design shall meet the process requirement and provide stable and flexible tower operation.

Reboilers are used to generate a flux of vapor to feed to a distillation tower; the vapor rises up the tower contacting a downwards-flowing liquid stream.2 (Palen, 1983) Reboiler types can be classified by circulation and reboiler position. The reboiler can be either natural circulation with available liquid head or forced circulation with a pump. They can be installed either horizontally or vertically. The process or logic flow for selecting reboilers is described in Figure 1. Appendix A(Chen, 2001) describes the different advantages and disadvantages of the

[1] Hydrocarbon Processing, July 2001, E. Chen
[2] Palen, J. W. (1983) Shell-and-tube reboilers, Heat Exchanger Design Handbook. Section 3.6. Hemisphere Publishing Corporation, New York.

various types of reboilers. For the process utilized in the sulphur recovery unit at Client A, a kettle boiler was designed into the process.

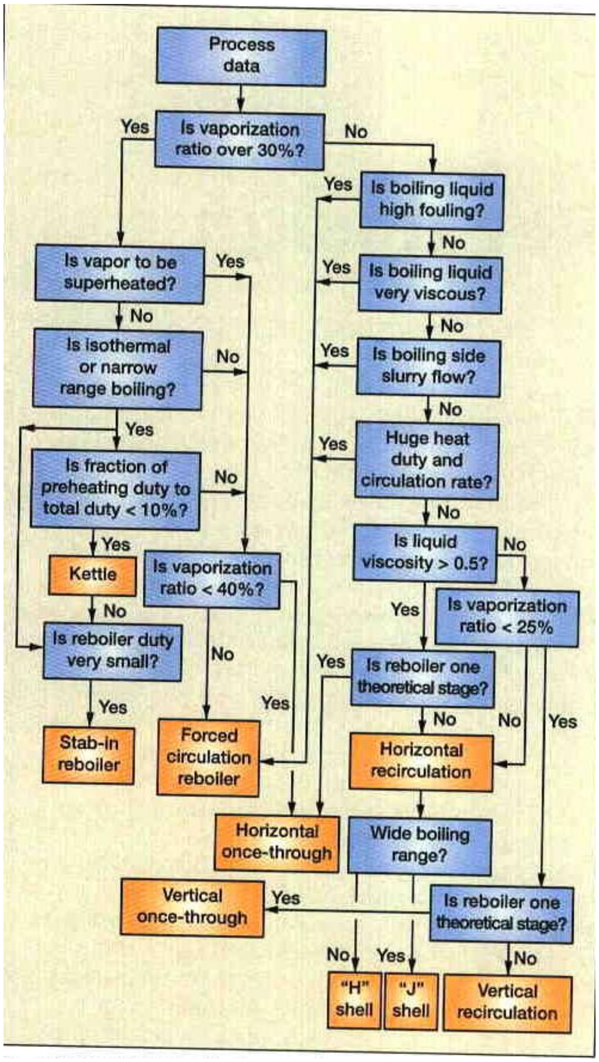

Figure 1 Flow Chart for Selecting Reboilers (Chen, 2001)

1.2. Kettle Reboilers

The layout of the kettle reboiler is illustrated schematically in figure 2. Liquid flows from the column into a shell in which there is a horizontal tube bundle, boiling taking place from the outside this bundle. The vapor passes back to the column as shown. Kettle reboilers are widely used in the petroleum and chemical industries; their main problems are that of ensuring proper disentrainment of liquid from the outgoing vapor and the problem of the collection of scale and other solid materials in the tube bundle region over long periods of operation; hence, the maintenance of the reboiler by opening it and pulling the bundle out for inspection and cleaning.

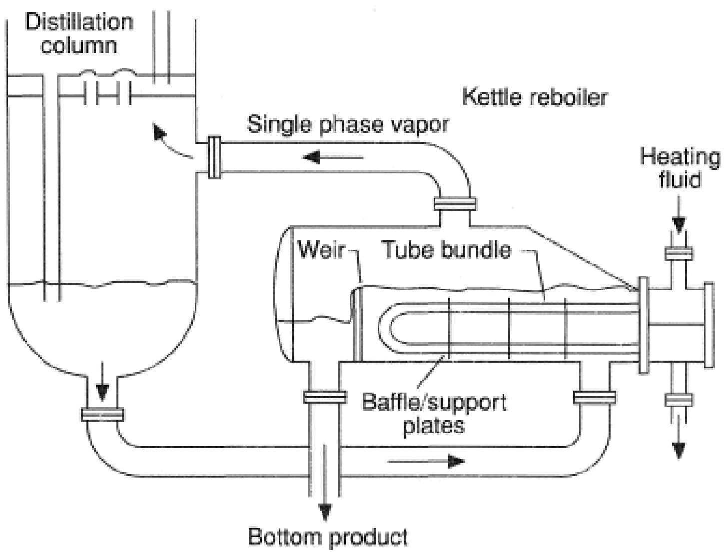

Figure 2 Kettle reboiler (Whalley & Hewitt, 1983)

2. Background

A sulphur recovery unit (SRU) utilizes the claus process to help remove the H_2S from the process. "The task of Claus processes is to recover elemental sulphur from hydrogen sulphide and, more generally, from by-product gases originating from physical and chemical gas and oil treatment units in refineries, natural gas processing, and gasification plants, to quote a few" (Signor, 2010). The multi-step claus process recovers sulfur from the gaseous hydrogen sulfide found in raw natural gas and from the by-product gases containing hydrogen sulfide derived from refining crude oil. The claus technology can be divided into two process steps, thermal and catalytic, both designed to yield more sulfur.

Industrial hygiene hazards that are associated with maintenance work are chemical (toxicological effects of H_2S) and physical (radiation from NORM's, ergonomics and noise).

2.1. Toxicological Hazards of Process

The operational plant that the maintenance was completed in contained a kettle reboiler, which is used to generate a flux of vapor to feed to a distillation tower. The Kettle Reboiler in this process contains H_2S within the process equipment. This chemical poses an inherent risk to humans when mitigations are not put into place. Hydrogen Sulphide is one of the most deadly occupational hazards in the oil and gas industry. It is referred to by many names: H_2S, sour gas, sewer gas, stink damp, swamp gas and manure gas.

Hydrogen sulfide occurs naturally in crude petroleum, natural gas and hot springs. Due to its extreme toxicity, employers must ensure that workers who may be exposed to H_2S gas are able to recognize its lethal effects. Procedures must be in place for activities where H_2S may be present as well as to ensure that victims who are overcome are rescued and given first aid. As shown in Table 1, H_2S has many properties which make it a dangerous chemical if proper mitigations are not in place.

Table 1 Properties of Hydrogen Sulfide (CDC, 2015)

Color	Colorless
Odor	Very offensive, commonly referred to as odor of rotten eggs at low concentrations, no odor at high concentrations, due to sense of smell being deadened
Vapor density	1.189 (Air = 1.0). H2S in its pure form is heavier than air
Explosive limits	4.3 to 46.0 percent by volume in air
Auto ignition temperature	260^{o}C
Flammability	Forms explosive mixture with air or oxygen
Water Solubility	2.9 percent (2.9 g/100 mL water at 20^{o}C)
Reactivity	Can react with iron to produce iron sulfide which will ignite in the presence of air unless it is kept wet (found as a brown/black deposit in vessels, tanks, pipes, fittings and exchange bundles).

The predominant exposure route for H_2S is through inhalation, as the majority of the time H_2S is encountered, it is in gaseous form. This is the same reason that ingestion or injection has a low likelihood as the exposure route. Skin contact as a route of exposure is most likely to occur if there is a release from a compressed gas cylinder; in which case, inhalation would also occur.

Through the exposure route of inhalation, H_2S enters the circulation directly across the alveolar-capillary barrier in the lungs, where it is dissociated in part into the sulfide ion, HS.

Some of the gas remains as free H_2S in the blood and this interacts and forms methyl sulfides; which, in turn bond to haeme compounds and are then metabolized via oxidation into sulfate. (Pietri, Román-Morales , & López-Garriga , 2011)

The critical target enzyme of the sulfide ion is cytochrome oxidase (a family of related enzymes that constitutes the electron transport system in oxidative phosphorylation). The effect of this is the same as oxygen deprivation or asphyxiation except that it may act more quickly (Pietri, Román-Morales , & López-Garriga , 2011).

2.1.1. Acute and Chronic Toxicity of H_2S

Acute toxicity can be defined as the adverse effects resulting from a single dose or single exposure to a substance. (Anna, 2011)[3]

Exposure to low concentrations of H_2S may cause irritation to the eyes, nose, or throat. It may also cause difficulty in breathing for some asthmatics. Brief exposures to high concentrations of H_2S (greater than 500 ppm) can cause a loss of consciousness and possibly death. In most cases, the person appears to regain consciousness without any other effects. However, in many individuals, there may be permanent or long-term effects such as headaches, poor attention span, poor memory, and poor motor function.

No health effects have been found in humans exposed to typical environmental concentrations of hydrogen sulfide (0.00011–0.00033 ppm). (The Agency for Toxic Substances and Disease, 2006)[4]

Table 2 describes the symptoms and effects for acute exposure to H_2S.

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[3] Anna, Daniel (2011), *The Occupational Environment-Its Evaluation, Control, and Management,* ***3rd edition,*** *pg1587*
[4] Agency for Toxic Substances and Disease Registries. (July 2006) Hydrogen Sulfide. *Retrieved on January 3, 2014 from* http://www.atsdr.cdc.gov/toxfaqs

Table 2 Acute Toxicity Symptoms and Effects of H2S

Concentration (ppm)	**Symptoms/Effects**
0.00011-0.00033	Typical background concentrations
0.01-1.5	Odor threshold (when rotten egg smell is first noticeable to some). Odor becomes more offensive at 3-5 ppm. Above 30 ppm, odor described as sweet or sickeningly sweet.
2-5	Prolonged exposure may cause nausea, tearing of the eyes, headaches or loss of sleep. Airway problems (bronchial constriction) in some asthma patients.
20	Possible fatigue, loss of appetite, headache, irritability, poor memory, dizziness.
50-100	Slight conjunctivitis ("gas eye") and respiratory tract irritation after 1 hour. May cause digestive upset and loss of appetite.
100	Coughing, eye irritation, loss of smell after 2-15 minutes (olfactory fatigue). Altered breathing, drowsiness after 15-30 minutes. Throat irritation after 1 hour. Gradual increase in severity of symptoms over several hours. Death may occur after 48 hours.
100-150	Loss of smell (olfactory fatigue or paralysis).
200-300	Marked conjunctivitis and respiratory tract irritation after 1 hour. Pulmonary edema may occur from prolonged exposure.
500-700	Staggering, collapse in 5 minutes. Serious damage to the eyes in 30 minutes. Death after 30-60 minutes.
700-1000	Rapid unconsciousness, "knockdown" or immediate collapse within 1 to 2 breaths, breathing stops, death within minutes.
1000-2000	Nearly instant death

Chronic toxicity can be defined as adverse health effects that can occur from prolonged, repeated exposure to relatively low levels of a substance; might have a chronic effect from an acute exposure. (Anna, 2011)[5]

[5] Anna, Daniel (2011), *The Occupational Environment-Its Evaluation, Control, and Management*, ***3rd edition,*** *pg1602*

The acute toxic effects of hydrogen sulfide have been known for decades. However, studies investigating the adverse health effects from chronic, low-level exposure to H_2S are limited. (Legator MS, 2001)[6]

Generally, chronic exposure to low level concentrations of H_2S is associated with neurological symptoms that include fatigue, loss of appetite, irritability, impaired memory, altered moods, headaches, and dizziness. At persistent concentrations of 0.250 to 0.300 ppm (250 to 300 ppb), the rotten egg odor of H_2S creates a nuisance to communities, and exposure to such concentrations has been documented to affect quality of life by causing headaches, nausea, and sleep disturbances.

Acute and chronic toxic effects of H_2S are shown in Appendix B taken from a study done at the University of California (Skrtic, 2006).

Dose response describes an effect where with an increasing dose, there are greater biological effects elicited. (Anna, 2011)[6] From this, a graphic representation can be made in the form of a dose response curve. This curve relates the biologic response to the concentration of the contaminant and time of exposure; which, when multiplied, determines the dose.

The dose-response curve for lethality is extremely steep for H_2S. The primary determinant of toxicity is the concentration rather than the duration of exposure[7]. (Anna, 2011) Higher concentrations of H2S gives little margin of safety.

The following three reasons explain why H2S is an exceptionally difficult gas from which to escape:

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[6] US National Library of Medicine National Institutes of Health, (March 2001), Hydrogen Sulfide, Retrieved on January 3, 2015 from http://www.ncbi.nlm.nih.gov/pubmed/11339675

[6] Anna, Daniel (2011), *The Occupational Environment-Its Evaluation, Control, and Management,* ***3rd edition,*** *pg1611*

[7] Anna, Daniel (2011), *The Occupational Environment-Its Evaluation, Control, and Management,* ***3rd edition,*** *pg1672*

1) Olfactory paralysis at higher exposure levels quickly ends perception of the characteristic smell of rotten eggs.
2) There is inadequate warning of the presence of H_2S despite the low odor threshold because of this paralysis.
3) The loss of consciousness often associated with overwhelming exposure reduces chances of flight.

Target organs are the organ of the body which are most affected by exposure to a substance. The target organs of H_2S are the eyes, respiratory system and the central nervous system.

With acute exposures to high concentrations of H_2S, numerous respiratory effects are observed. Single exposures greater than 700 ppm H_2S are considered to cause rapid respiratory failure. Other respiratory effects of single exposures to high concentrations of H_2S include non-cardiogenic pulmonary edema, sore throat, cough, and dyspnea.

Although the exact mechanism is not known, there is strong evidence to suggest that the rapid respiratory failure and possibly the pulmonary edema are secondary to the action of H_2S on the respiratory center of the brain. (Skrtic, 2006) Respiratory failure and pulmonary edema may be due to inhibition of cytochrome oxidase in lung mitochondria, which is the terminal step in oxidative metabolism, resulting in tissue hypoxia.

Available information on the neurotoxic effects of single exposures to high concentrations of H_2S in humans comes primarily from case reports[8] (Chou, 2003). In most instances, exposure concentrations were either unknown or estimated. The neurological effects following single inhalation exposures to high concentrations of H_2S may be permanent or persistent.

Urine is the primary route of elimination following H_2S exposure. Following exposure to sodium sulfide via i.v. and subcutaneous (s.c.) routes or exposure to H_2S by inhalation routes in dogs and rats the majority of the dose (70-99%) was eliminated in the urine by 24 hours post-exposure. (Strickland, Cummings, Spinnatti III, Liccione, & Foureman, 2003)[9]

2.1.2. Occupational Exposure Limits of Hydrogen Sulphide

The Alberta Occupational Health and Safety (OH&S) 8 hour occupational exposure limit (OEL) threshold was set so there will be no adverse effects if exposed. (Government of Alberta, 2009) This Act is the one in which Client A and Company B must adhere to.

There are three other bodies in North America that meet or exceed the Alberta OH&S guidelines for H_2S OEL. :

1) Occupational Safety and Health Administration (OSHA, 2015) - OSHA is the main federal agency charged with the enforcement of safety and health legislation in the United States
2) National Institute for Occupational Health and Safety (CDC, 2015) - The National Institute for Occupational Safety and Health (NIOSH) is the U.S. federal agency that conducts research and makes recommendations to prevent worker injury and illness.
3) American Conference of Industrial Hygienists (ACGIH, 2015) – The American Conference of Industrial Hygienists (ACGIH) is a member-based organization that advances occupational and environmental health.

[9] EPA, (June 2003) Toxilogical Review of Hydrogen Sulfide

Table 3 displays the regulatory limits for these 3 bodies and the Alberta OH&S. ACGIH has the most stringent 8 hour OEL, with Alberta following suit. OSHA and NIOSH do not seem to have a 8 hour occupational exposure limit, just a ceiling limit that is not to be exceeded unless no other measures occurred during the 8 hours period. These levels are still below what would be deemed as chronic exposure.

Table 3 Regulatory Limits for H2S

	8 hr Occupational Exposure Limit	**Ceiling / Peak Exposure**
OSHA	NA	Exposures must not exceed 20 parts per million (ppm) (ceiling) with the following exception: if no other measurable exposure occurs during the 8-hour work shift, exposures may exceed 20 ppm, but not more than 50 ppm (peak), for a single time period up to 10 minutes. (OSHA, 2015)
NIOSH	NA	10 ppm for 10 min. maximum
ACGIH	1 ppm	5 ppm for 15 min. maximum
Alberta OH&S	10 ppm	15 ppm for 15 min. maximum

To prevent exposure and the acute and chronic effects of H_2S, atmospheric monitoring will have to occur to ensure the levels are within the permissible range. If not, mitigations will have to be put in place, such as self-contained breathing apparatus. Often, a combination of respiratory protection and atmospheric monitoring is put into place as other hazards such as LEL's (lower explosive limit of hydrocarbons) and low oxygen content (both of which can be covered with respiratory protection or NORM (naturally occurring radioactive material) could exist.

2.2. Naturally Occurring Radioactive Material (NORM)

Naturally occurring radioactive material (NORM) is present to some degree in all produced petroleum fluids, as well as soil and rock removed from the earth. These include uranium, thorium, radium, and radon. The background concentration of NORM is typically low; however, higher levels may arise as the result of human activities.

In the oil and gas industry, NORM may be present in the liquids and gases from some geological formations. Scale from oil recovery brine, for example, may contain radium at much higher concentrations than the original water source. Radon gas in the natural gas streams concentrate as NORM in gas processing activities. Radon decays to lead-210, then to bismuth-210, polonium-210 and stabilizes with lead-206. Radon decay elements occur as a shiny film on the inner surface of inlet lines, treating units, pumps and valves associated with propylene, ethane and propane processing systems (Krieger, 2005).

NORM characteristics vary depending on the nature of the waste. NORM may be created in a crystalline form, which is brittle and thin, and can cause flaking to occur in tubulars. NORM formed in carbonate matrix can have a density of 3.5 grams/cubic centimeters and must be noted when packing for transportation. NORM scales may be white or a brown solid, or thick sludge to solid, dry flaky substances. (Krieger, 2005)

Cutting and reaming oilfield pipe, removing solids from tanks and pits, and refurbishing gas processing equipment may expose employees to particles containing increased levels of alpha emitting radionuclides that could pose health risks if inhaled or ingested.

The basic philosophy of worker protection from all radioactive materials, including NORM, is to maintain all exposures “as low as reasonably achievable” (ALARA). In other words, if it is feasible to avoid all unnecessary exposures above normal background levels, that is the preferred objective.

When working with NORM there are two possible sources of exposure to radiation: external radiation and internal radiation.

External radiation exposure occurs when personnel are exposed to gamma radiation from sources outside the body, which is measured in nanoSieverts per hour (nSV/hr). Client A and Company B use the following limits for gamma radiation: Any gamma radiation in excess of 150 nSv/hr triggers the need for further investigation (e.g. internal NORM survey) and any levels in excess of 500 nSv/hr would require tracking of worker time in those areas. Gamma radiation in excess of 2500 nSv/hr requires personal dosimeter radiation monitoring.

External radiation levels have been monitored at Client A and do not exceed the natural background levels (<150 nSv/hr). External radiation exposure can further be reduced via time, distance and shielding.

Internal radiation exposure occurs when NORM gets into the body, and is of far greater concern than external radiation exposure. Some radioactive isotopes may not be eliminated from the body for several decades, and a very large cumulative dose may build up. Inhalation and ingestion are the common routes of entry.

All feasible measures must be taken to prevent NORM particles from becoming airborne as industrial operations, such as welding, grinding or cutting can create an inhalation hazard.

Possible controls include using water to prevent materials becoming airborne, good housekeeping, and closure of emission points. If the dust cannot be controlled through these measures, workers must use respiratory protection.

Ingestion of NORM may occur when contaminants are deposited on clothing, PPE, or equipment and then transferred into the body. Possible controls include the use of disposable PPE and setting up control areas where workers are surveyed for contamination prior to leaving the control area. A half mask respirator will also eliminate the potential for ingestion as it creates a barrier for ingestion. Good housekeeping, personal hygiene, restrictions on eating, drinking, and smoking in workplace areas where contamination may be present will further reduce the risk.

If NORM is detected in the equipment, special precautions are required before the equipment is opened for repair, maintenance or inspection. These special requirements are all part of the Controlled Access Area.

Client A and Company B follow these steps:

- Norm Testing
- Labelling of contaminated equipment
- Setting of controlled area (Containment, flagging)
- Workers, tools and equipment decontamination. (Decontamination room, cleaning equipment on-site)
- Waste management
- Transportation and disposal site and
- Records keeping

If appropriate testing is done and controls to mitigate NORMs are put into place, the workforce will not be exposed to NORMs. Some of these controls include wetting the equipment (prevents dust), exposure time limited and respiratory protection.

2.3. Respiratory Hazards

Respiratory protection for respiratory hazards is an integral part of maintenance work to protect workers from airborne contaminants such as particulates, NORMs, fumes and vapors. It is frequently used to protect the workers from airborne contaminants they are working with or creating and while it is considered personal protective equipment and a last line of defense, it is still very important that it is utilized correctly.

Company B has a code of practice which applies to all employees who work in areas where exposure to respiratory hazards require the use of respirators. Respirators shall be used to protect employees from inhalation hazards when engineering control or substitution of less toxic materials is not feasible and in emergency situations. When respirators are to be used, all requirements of the code of practice are followed.

In order to determine the presence of respiratory hazards (ex. dust, asbestos, NORM, gas) and to assist in the selection of appropriate respiratory protection, a hazard assessment and evaluation of the work area must be performed prior to work commencement. The hazard assessment must identify:

a. What contaminant(s) are or may be present in the work area;

b. The physical state of the contaminant(s);

c. A measure of the contaminant(s);

d. Whether the atmosphere is oxygen deficient or oxygen rich (poses an explosion threat);

e. The occupational exposure limits of the contaminant(s);

f. If an immediately dangerous to life and or health (IDLH) atmosphere is present;

g. If there is an applicable health regulation or standard for the contaminant(s);

h. If the contaminant(s) have a known taste, smell or irritation;

i. Identify whether there is oil present, if the contaminant can be absorbed through, or is irritating to, the skin or eyes;

j. The need for emergency escape;

Upon completion of this assessment, the decision can be made as to whether respiratory protection is needed or not. Personnel conducting respirator selection should consider extraordinary circumstances in the operation that could adversely affect the function of a respirator, (i.e. extreme cold or radiant heat, above or below normal pressure conditions). Advice should be sought from the respirator manufacturer's technical experts where applicable. All respiratory protective equipment shall be appropriate to the hazards in accordance with CSA standard Z94.4-02, Selection, Use and Care of Respirators. Company B utilizes the flow chart[7] (Worksafe Alberta, 2013) illustrated in Figure 3 to determine which type of respiratory protection is required.

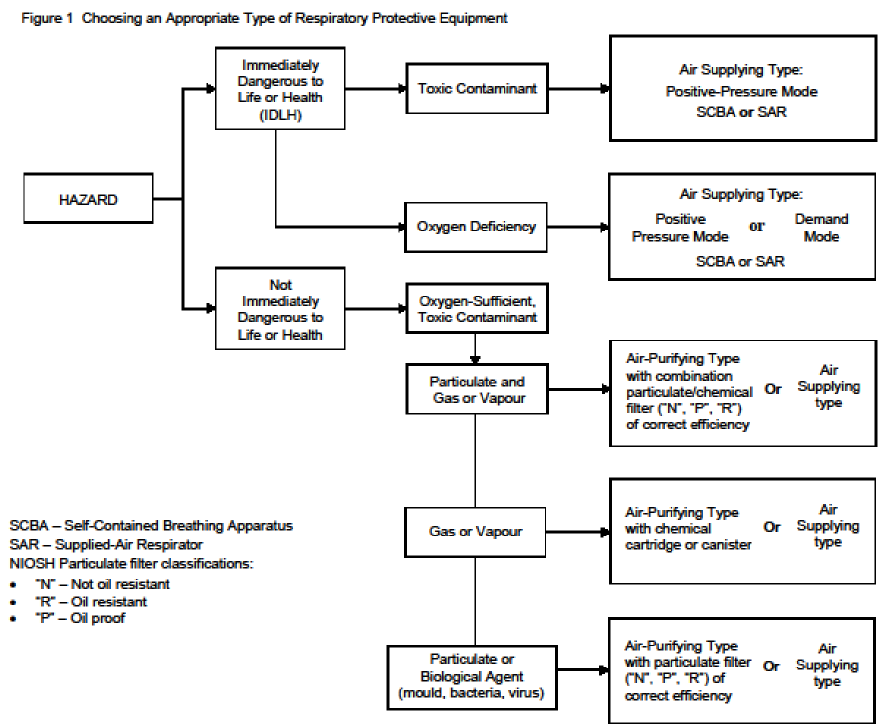

Figure 3 Choosing an Appropriate Type of Respiratory Protective Equipment

Additional considerations must be taken into account and include the following when selecting appropriate respiratory protection:

a. The length of time that the respirator will need to be worn;

[7] Retrieved from http://work.alberta.ca/documents/WHS-PUB_ppe001.pdf on January 29, 2015

c. The physical health and limitations of the individual who will use respiratory protection;

d. The functional and physical characteristics of the respiratory device;

There are 3 primary groups of respirators: air purifying respirators, air supplying respirators and special use respirators.

2.3.1. AIR PURIFYING RESPIRATORS

Air purifying respirators are available in two models; non-powered (relies on the breathing action of the wearer) and powered (contains a blower that passes surrounding air through the purifying component). Air purifying respirators are either ½ masks or full face; full face respirators cover the entire face and have the added benefit of built in eye protection.

With air purifying respirators, the air in the immediate surrounding area prior to being inhaled, is passed through a filter, cartridge or canister that remove particles, vapors, gases or a combination of these contaminants.

There are some limitations to air purifying respirators:

- Air purifying respirators require sufficient oxygen (19.5% - 23%)
- They cannot be used in IDLH atmospheres
- They have a maximum use concentration based on the contaminate toxicity and the type of face piece style and model used,
- They cannot be used for substances with poor warning qualities and cannot be used when there is high relative humidity.

2.3.2. AIR SUPPLYING RESPIRATORS

There are 3 different kinds of air supplying respirators

1) Self-contained (demand or pressure demand) (SCBA, self-contained breathing apparatus).

2) Supplied air (demand, pressure demand and continuous flow) (SABA, supplied air breathing apparatus).

3) Combination supplied air with auxiliary self-contained supply.

These respirators provide employees with clean breathing air from outside the work area. The air is carried through a breathing air cylinder or supply hose which are connected to the workers face piece. Pressure demand SCBA or a combination pressure-demand supplied air respirator with auxiliary self-contained air supply, with a minimum service time of 15 minutes, shall be used for entry into IDLH atmospheres.

Company B employees required to wear respiratory protection equipment are trained in the care, use, limitations and selection of the equipment. Training varies depending on the type of respirator required and the nature of the inhalation hazard. Specialized training is required prior to the use of SCBA and SABA respiratory systems; certification is mandatory. Client A provides training certification for all SCBA and SABA on this site.

Company B requires all employees that don respirators to complete a “respirator users medical screening” form before they are fit tested. The medical screening is a series of confidential questions regarding the workers’ health. Answers to these questions will determine if a worker needs to consult with a medical doctor for consent prior to donning respiratory protection. The screening is appropriate to the type of respirator being issued.

To ensure that the employee is able to use a respirator without serious difficulty, the following is taken into consideration when completing the medical screening process:

a. How often the respirator will be used and the activities the worker must do while wearing the respirator;

b. The health of the person;

c. The type of respirator to be worn;

d. The workplace conditions in which the respirator is used;

Company B utilizes a 3rd party company to perform quantitative fit testing for ½ mask, full face and breathing air.

Both company B and Client A employ quantitative fit testing methods to ensure a proper fit. A quantitative fit test (QNFT) is a type of respirator fitting test that numerically evaluates respirator fit, measuring the leakage into the respirator. It compares the respirator leakage with ambient concentrations of the test agent.

Company B uses 3M brand of half and full face air purifying respirators and Client A uses Scott brand breathing air masks.

A fit test is used to determine the ability of a user to obtain a satisfactory fit and an effective seal when using a tight fitting face-piece.

Fit testing is utilized when:

a. The respirator is first issued and annually thereafter;

b. If the respirator type changes;

c. If conditions at the worksite change;

d. If the worker's facial features change, i.e. scarring from an injury;

If a worker cannot pass a fit test, then that worker will not be required to wear respiratory protection with company B and will be put on a task that does not require the use of respiratory protective equipment. Different types of PPE and movement (ergonomics) can affect the fit of respiratory protection. It is because of this, that the PPE that will be worn and the potential movements are replicated during the fit test. Some of the movements of the workforce require extra monitoring in the field.

This is where ergonomic surveys are beneficial to complete to help identify ergonomic hazards and find solutions to mitigate them. .

2.4. Ergonomics

Ergonomics is the study of people and their interaction with the elements of their jobs or tasks, including equipment, tools, facilities, processes, and environment. It is a multidisciplinary field of study that integrates engineering, medicine, design, and industrial psychology.

In a more practical sense, ergonomics is the science of human comfort. When aspects of work or the workplace challenge or stress the human body beyond its capabilities, the result is often a musculoskeletal injury (MSI). MSIs are also known by several other names, including:

- O/E (overexertion injury)
- RSIs (repetitive stress or repetitive strain injuries)
- ASTDs (activity-related soft tissue disorders)
- CTDs (cumulative trauma disorders)
- MSDs (musculoskeletal disorders)

Whatever name is used, these injuries belong to a group of sprain and strain injuries that can affect muscles, nerves, tendons, ligaments, joints, cartilage, blood vessels, or spinal discs in the body. Musculoskeletal injuries do not include injuries resulting from slips, trips, falls, cuts, motor vehicle accidents, or similar accidents; however, a close look at the causes of these acute injuries often reveals design problems that can be corrected. Section 1 of the OHS Code defines a musculoskeletal injury as an injury to a worker involving the muscles, tendons, ligaments, joints, nerves, blood vessels or related soft tissues that is caused or aggravated by work and includes overexertion and overuse injuries.[8] (Government of Alberta, 2009)

To help avoid MSI's, work demands should not exceed the physical capabilities of the worker.

The purpose of an ergonomics program is to apply ergonomics principles to the workplace to help reduce the number and severity of MSI's. This helps decrease workers' compensation claims and other costs, while increasing productivity, quality, and efficiency. An ergonomically sound work environment maximizes worker comfort while minimizing the risk of MSI.

Musculoskeletal injuries can be associated with most jobs; however the mere presence of MSI risk factors may not in itself result in an injury. It depends on, for example, how great the force (The amount of muscular effort required to perform a task) applied is and how long the worker is exposed to the risk. It can also depend on individual characteristics that vary from worker to worker (such as height, gender, age and the body's ability to deal with the risk factors). Risk factors to consider when assessing MSI include:

a. Force.

b. Repetition.

c. Work posture.

d. Local contact.

e. Reaching.

f. Working height.

g. Floor surface.

h. Size and shape of objects.

[8] Alberta Occupational Health and Safety Code, Part 1 (2009)

i. Weight distribution, etc.

Note: For each of these risk factors, it is important to consider duration (how long) and magnitude (how much).

Company B's ergonomic program includes the following components:

- Training
- Safe lifting practices
- Manual lifting procedure
- Preventing musculoskeletal injuries
- Early signs, symptoms and effects of MSI's
- MSI controls

The workers that are hired by Company B review Company B's ergonomic program in the orientation, with the focus being on manual lifting as this occurs frequently within Company B's work scope.

Most manual lifting incidents are due to improper lifting methods. Always consider mechanical advantages to lifting a load prior to manual lifting. The following safe lifting practices are used:

a. Before manually lifting, lowering, pushing, pulling, carrying, handling or transporting a load, a field level risk assessment (FLRA) must be completed and the following considered:

i. The weight of the load.

ii. The size of the load.

iii. The shape of the load.

iv. The number of times the load will be moved.

v. The manner in which the load will be moved.

b. Know your limits when moving heavy or bulky objects.

c. Get help if the load is too heavy, awkward or if conditions are slippery, congested, etc.

d. Use equipment designed to mechanically assist with the lift.

e. Never try to catch a falling load.

The procedure the Company B employs is:

a. Position your body close to the load that is to be lifted.

b. Take a wide stance, with the load between the knees if possible.

c. Bend your knees. (Bending at the waist to lift a load is not permitted.)

d. Keep the lower back straight. (The risk of injury increases when lower back is rounded.)

e. Keep your head up. (The more vertical your posture is, the lower the risk of injury.)

f. Lift slowly by straightening your legs. Keep your back relatively straight. Your leg muscles, not your back, should do the work.

g. Always keep your shoulders in line with your feet.

h. Never twist while lifting or carrying a load, even light loads. (Twisting significantly increases the risk of injury.)

i. Proper lowering is as important as the lift. Bend the knees, keep the back straight and breathe out as you begin lowering the load (dropping or throwing a load is hazardous.)

The ergonomic practices that Company B employs will be assessed for workplace exposure. This program is one of two programs that will be assessed through the monitoring of the work force; the other program is the hearing conservation program or noise.

2.5. Noise

"Noise is virtually everywhere"[9] (Berger, 2003)

Noise is one of the most common workplace hazards. Workers in many industries and occupations in Alberta are exposed to noise levels that are so high that their hearing can be damaged. Sometimes the noise may not even be considered to be noise — such as the very loud music to which entertainers and food and beverage servers are exposed in bars and nightclubs. If the sound is loud enough and workers are exposed to it for long enough, their hearing will be damaged. Fortunately, work-related hearing loss is preventable.

Employers in Alberta are responsible for minimizing the noise hazard at their workplaces and must comply with the province's Occupational Health and Safety (OHS) legislation.[10] (WorkSafe Alberta, 2015)

Table 4 (Government of Alberta, 2009) displays the exposure level and the exposure duration workers must adhere to if they are working in the province of Alberta.

Table 4 Schedule 3, Table 1 of the OHS Code Occupational exposure limits for noise

Exposure level (Government of Alberta, 2009) (dBA)	Exposure duration
82	16 hours
83	12 hours and 41minutes
84	10 hours and 4 minutes
85	8 hours
88	4 hours
91	2 hours
94	1 hour
97	30 minutes
100	15 minutes
103	8 minutes
106	4 minutes
109	2 minutes
112	56 seconds
115 and greater	0

[9] The Noise Manual, 5th Edition, Elliot Berger et Al, 2003

[10] Retrieved from http://work.alberta.ca/documents/WHS-PUB_hs003.pdf on February 10, 2015

Hearing conservation is achieved through preventative measures. To reduce occupational / noise induced hearing loss, all employees who work in potentially noisy areas are provided hearing protection, training and regular audiometric testing. Company B's audiometric testing is sourced out through a 3rd party provider.

The hierarchy of controls is used to eliminate or minimize noise hazard exposure in the workplace. When such controls are not practical or applicable, hearing protection is used to reduce or eliminate exposure to noise hazards.

The hearing protectors selected must meet the requirements of CSA Standard Z94.2-02 (CSA Group), *Hearing Protection Devices – Performance, Selection, Care and Use*. This standard provides performance requirements for personal hearing protection devices. The standard classifies muffs and earplugs as Class A, B or C depending on the level of protection they provide. Class C provides the least degree of protection while Class A provides the greatest. Table 5 of Schedule 3 (Government of Alberta, 2009), indicates the class of hearing protection to be used at various noise levels.

The classification of hearing protectors is based on how much they attenuate or reduce sound levels at nine different frequencies: 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 3150 Hz, 4000 Hz, 6300 Hz and 8000 Hz. The manufacturer of the hearing protection must provide this information to the equipment user.

The CSA standard has introduced a 0 to 4 grading system for hearing protection devices. A device with a "0" grading provides the least protection, a device with a "4" grading provides the most. Grades are assigned to hearing protection devices based on laboratory attenuation measurements. The purpose of using a grade system is to be able to make a "go" or "no-go" determination i.e. either the hearing protection is right for the noisy situation or it is not. Such absolute decisions require the actual hazard to be known i.e. both sound pressure levels and duration of exposure must be assessed[11]. (Government of Alberta, 2009)

Table 5 Selection of Hearing Protection Devices

Maximum Equivalent Noise Level (dBA)	CSA Class of Hearing Protection	CSA Grade of Hearing Protection
≤90	C, B, or A	1, 2, 3 or 4
≤95	B or A	2, 3 or 4
≤100	A	3 or 4
≤105	A	4
≤110	A Earplug + A or B Ear Muff	3 or 4 earplug + 2, 3, or 4 earmuff
>110	A earplug + A or B earmuff and limited exposure time to keep sound reaching the worker's ear drum below 85 dBA	3 or 4 earplug + 2, 3, or 4 earmuff and limited exposure time to keep sound reaching the worker's ear drum below 85 dBA

2.5.1. Use of Dual Hearing Protection

As per Table 5, once a worker is exposed to noise greater than 105 dBA, the worker must wear both a plug and a muff (dual hearing protection). At noise levels greater than 110 dBA, dual hearing protection must be worn *and* time of exposure reduced.

When dual hearing protection is worn, the noise reduction (attenuation) at each frequency is not the sum of the individual hearing protector's attenuations, it is usually much less. This is due to the fit of the hearing protectors and the volume of air trapped between them as well as limitations created by bone conduction. Bone conduction allows sound energy to be transmitted through the bones and tissues of the skull to the inner ear, bypassing the hearing protector. It poses a limitation on the protection that any hearing protector can provide, regardless of how well it seals to the ear canal and prevents sound from entering the ear.

[11] Alberta Occupational Health and Safety Code (2009)

3. Kettle Reboiler Isolation

Isolation must be achieved on any process equipment that contains energy or harmful substances that may cause injury to personnel and/or damage to equipment. To achieve isolation on the equipment, the following procedure is followed:

1) Client A's operations group will be notified of the equipment/system to be isolated for a job.

2) Client A's operations group then opens electrical circuits, isolates, de-pressures, and decontaminates (if necessary) the equipment/system prior to tagging to establish a safe work envelope.

3) Client A's operations group will hang their tags/locks, fill out the isolation list and fill out the isolation card. This includes signing under "authorized signature signifies all isolations complete". The accepted practice for securing a valve is to use a steel cable tie, or a lock and chain and to tag it. Where blinds provide part of the safe work envelope, the blind(s) will be tagged and documented. The isolation point description and tag numbers on the isolation list will coincide with the actual isolation points and tags in the field.

4) Company B's maintenance personnel wanting to do a job on the system will be given the opportunity during the job site visit to accompany Client A's operations group to all of the tagged and secured energy isolation locations. Company B's maintenance members wanting to do individual securing of an energy isolating point must be allowed to do so.

5) All “jobs to be done” by Company B’s maintenance personnel within an existing safe work envelope will be added to the isolation card under “jobs to be done” and signed in under “acceptance of isolation”.

6) Company B’s maintenance members may add a new job under “jobs to be done” within an existing safe work envelope if accepted by Client A’s operations group.

7) Company B’s maintenance personnel signing on to the isolation card - acceptance of isolation section are verifying they have confirmed that all energy sources are effectively isolated.

   - Verification may be achieved by testing circuitry, attempting to cycle machinery, visual inspection, monitoring movement or discharge, observing bleeds, gauges or indicators, or other equally effective approaches.

   - Company B’s maintenance member is not required to confirm that Client A’s operations group physically placed the isolation points in the correct location; however Company B’s maintenance member is required to ensure placement of the isolation points has resulted in the energy sources being effectively isolated.

8) When removing craft locks/tags, Company B’s maintenance member must be of the same trade/craft that installed them.

9) Company B’s maintenance member will notify Client A’s operations group when the job is complete and the job site is cleaned up.

10) Company B’s maintenance personnel signing off their trade on the isolation card must ensure that their trade’s job is complete and locks (if applicable) are removed.

11) Prior to clearing isolations Client A’s operations group visually verifies flange tightness and integrity tagging**.**

12) When all the “jobs to be done” have been signed off on the isolation card Client A’s operations group will remove their tags and locks from the system and then sign off the isolation card.

For this particular job, Appendix C depicts the blind points, Appendix D shows the blind list for isolation and Appendix E shows the blind list for entry.

4. Research Design and Methodology

To complete this research, participation was needed from Client A’s operations group and Company B’s maintenance group. Access was needed into the live unit during isolation and maintenance. With this access, testing and research was able to occur over a 3 day period.

4.1. Survey Equipment – Gas and Vapour Measurement

Work area gas and vapor surveys were conducted. The LEL % was used to relate the concentration measured to applicable gas and vapor standards, of which concentrations are expressed as LELs.

The equipment needed to complete these surveys is shown in Table 6 and figures 12 through 14.

Table 6 Toxicological Survey Equipment

Instrument Make and Model	Serial Number	Calibration Date	Calibration Due Date	Calibration Method	Span Gas Used
BW GasAlertQuattro Multi Gas Detector	HM12-H574007	February 10, 2014	February 10, 2015	As per BW Operating Manual	CALIBRATION GAS CYLINDER, HYDROGEN SULFIDE (H2S) 10PPM / AIR, (2AL) 34 LTR, CZF2A310015
BW GasAlert Docking and Calibration Station	H411-H124440	February 8, 2014	February 8, 2014	As per BW Operating Manual	CALIBRATION GAS CYLINDER, HYDROGEN SULFIDE (H2S) 10PPM / AIR, (2AL) 34 LTR, CZF2A310015
BW GasAlertClip Extreme 2-Year Single Gas Detector	HM12-H573997	February 8, 2014	February 8, 2015	As per BW Operating Manual	CALIBRATION GAS CYLINDER, HYDROGEN SULFIDE (H2S) 10PPM / AIR, (2AL) 34 LTR, CZF2A310015
BW GasAlert Docking and Calibration Station	HM12-H574109	February 6, 2014	February 6, 2015	As per BW Operating Manual	CALIBRATION GAS CYLINDER, HYDROGEN SULFIDE (H2S) 10PPM / AIR, (2AL) 34 LTR, CZF2A310015

Figure 4 BW GasAlert Quattro Multi Gas Detector (BW Gas Monitors, 2015)

Figure 5 Docking & Calibration Station (BW Gas Monitors, 2015)

Figure 6 BW GasAlert Clip Extreme (BW Gas Monitors, 2015)

4.1.1. Gas & Vapor Survey Methodology

The initial plan for gas and vapor monitoring was to survey the atmosphere as Company B's maintenance workers broke open the flanges (workers need to break apart the flange to put in a blind to achieve isolation); however, this was not possible as Client A's operations group would only permit the maintenance workers within the area due to potential H_2S presence. In order to get a representative sample of what the atmosphere was, the workers were each given a BW GasAlert Extreme to wear (see Figure 14). These monitors survey the H_2S in the atmosphere and let the workers know if they are exposed to a concentration greater than 10 ppm, which is the 8 hour occupational exposure limit in Alberta. If the monitors alarm, the procedure is to leave the work area and be taken to the health center to ensure the workers are okay.
In addition, client A's operations group used the BW GasAlert Quattro (See Figure 12) to survey the work area every two hours, transposing these readings onto the hot work permit.

The task of blinding out this equipment was given to two boilermakers and two pipefitters from Company B. There were 10 blind locations in total (See Appendix C) and they were spread out on multiple levels. As there was a potential for hydrogen sulphide in the atmosphere, operations deemed that the workers had to wear SCBAs for all of the blinds until it was demonstrated that there were no contaminants at the work areas. This ensured there was no exposure to any atmospheric contaminants.

The blinding process took approximately 1 full work shift, or 10 working hours. The data from the workers personal H_2S monitors and the data Client A's operations group gathered was analyzed to further define the atmosphere they were working in.

4.2. NORM Survey Equipment

Company B does not have NORM surveying capabilities; therefore, the process that is relied on is Client A's. A radiation survey meter capable of operating in either rate meter or scalar mode with the ability to accurately measure gamma radiation dose rates in nano-sieverts per hour (nSv/hr) or equivalent and contamination levels in counts per minute (CPM) is required for this survey. The survey meter should have both a gamma scintillation probe and pancake contamination probe.

4.2.1. NORM's Survey Methodology

For this project, the NORM's survey equipment that the client provided was not utilized as Client A determined that there was a very limited chance of there being NORM's present in the equipment in this unit, based on historical data and past surveys.

As a result of this, a NORM's survey was not performed because we could not utilize the NORM's equipment, nor get a permit for the testing.

4.3. Respiratory Protective Equipment

No survey is utilized for the respiratory protective equipment. Company B's maintenance members have all been quantitatively fit tested by a 3rd party provider and trained through the client on the SCBA system used on this site, Scott 4.5 SCBA with AV2000 masks.

4.4. Ergonomics Survey

The work location was outdoors and work was conducted during daylight hours. The workers used a scaffold to access the work area, which eliminated the need for ladders and over extension. The work did involve tools and the workers were required to lift, twist, stand and crouch to complete the work. The tool used was a rad torque wrench (weight is approximately 7 kilograms), tensioning equipment (weight is approximately 20 kilograms) and wrenches (weight will vary from 0.5 kilograms to 2 kilograms).

A rad torque wrench is a planetary gear reduction torque multiplier that is designed to deliver a powerful, accurate and safe torque load.

Tensioning equipment is equipment that uses high pressure hydraulic oil from a pump to apply an accurate, axial load to a fastener. Once the system reaches a predetermined pressure, an operator uses a small bar to run the nut down by hand. This is easily accomplished because there is no load on the nut. After the nut is in place, the hydraulic pressure is released, transferring the axial load to the fastener, thereby tightening the nut (tensioning).

The area had red ribbon around it to keep people out due to the potential hazards within (H_2S, noise and moving equipment). The workers were observed outside of the red ribbon to determine the length of task, repetitiveness, motions used and what mitigations are in place to ensure the motions are ergonomically sound.

Quantifying ergonomic results on the tasks such as the ones performed by this workforce is completed by surveying the workers using the rapid entire body assessment (REBA) tool REBA has been developed to fill a perceived need for a practitioner's field tool, specifically designed to be sensitive to the type of unpredictable working postures found in health care and other service industries.[12] (Hignett S, 2000)

This survey considers critical tasks of a job and then for each task, assess the posture factors by assigning a score to each region. The data sheet in Appendix F provides a format for this process and the math involved. To use the data sheet:

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[12] Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10711982 on March 5, 2015

1) Score the Group A (Trunk, Neck and Legs) postures and the Group B (Upper Arms, Lower Arms, and Wrists) postures for left and right. For each region, there is a posture scoring scale plus adjustment notes for additional considerations.
2) Then score the load / force and coupling factors.
3) Finally, score the activity
4) Find the scores from Table A for the Group A posture scores and from Table B for the Group B posture scores. The tables follow the data collection sheet.
5) Score A is the sum of the Table A score and the load / force score. Score B is the sum of the Table B score and the coupling score for each hand.
6) Score C is read from Table C, by entering it with the Score A and the Score B.

The REBA score is the sum of the Score C and the Activity score. The degree of risk is found in the REBA decision table as shown in Figure 9.

Score	Level of MSD Risk
1	negligible risk, no action required
2-3	low risk, change may be needed
4-7	medium risk, further investigation, change soon
8-10	high risk, investigate and implement change
11+	very high risk, implement change

Figure 7 Level of Musculoskeletal Disorder Risk

For this tool, the assessment was prepared by interviewing the workers being evaluated to gain an understanding of the job tasks and demands, and observing the worker’s movements and postures during several work cycles.

Selection of the postures evaluated was based on:

1) The most difficult postures and work tasks (based on worker interview and initial observation)
2) The posture sustained for the longest period of time, or
3) The posture where the highest force loads occur

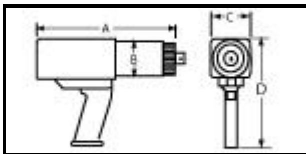
After interviewing the workers, it was determined that the only concern with this work was when they were utilizing the rad gun due to the position their body was in. They were not concerned about the tensioning equipment as it was easy to handle and the distance travelled when used was short. Likewise, they were not concerned for the operation of the bundle puller because the crane supports the load and the worker just operates the levers as the machine pushes and pulls the bundle in and out of the shell.

The rad gun utilized in this task was the Rad50 Pneumatic Torque Wrench[13], (Global Mining Products, 2015) shown in the figure below.

Figure 8 RAD-50 Pneumatic Torque Wrench

This rad gun weighs approximately 15 kilograms and has the following dimensions:

[13] Retrieved from http://www.globalminingproducts.com/RAD50.html on February 18, 2015



RAD 50 Dimensions
A: 13.9 "
B: 4.0 "
C: 3.7"
D: 10.4"

Figure 9 Rad50 Dimensions

Based on the weight and dimensions of this tool, the evaluation is done where the worker is operating the rad gun at chest level for sustained periods of time.

4.5. Noise Survey Equipment

Sound pressure level readings were taken at an A weighting (the A-weighting filter covers the full audio range - 20 Hz to 20 kHz and the shape is similar to the response of the human ear at the lower levels) and C weighting (a standard frequency weighting for sound level meters, commonly used for higher level measurements and peak sound pressure levels) in several locations using a calibrated Quest[14] Type II 2100 sound level meter as shown in Table 7. The sound level meter (SLM) was calibrated using the Quest calibrator prior to taking readings and following the monitoring event. The meter readings fell within the accepted calibration ranges at both the pre-survey calibration and the post-survey calibration. The SLM was set to slow response, SPL mode, and the 50 – 120 dB range.

Table 7 Noise Survey Equipment

Instrument Make and Model	Serial Number	Calibration Date	Calibration Due Date
Quest Model 2100 Sound Level Meter (Type 2)	DAJ030073	April 10, 2014	April 10, 2015
Quest Model QC-10/QC-20	QIJ050151	December 18, 2013	December 18, 2014

[14] Quest is a registered trademark of Quest Technologies, Oconomowork, WI

Acoustic Calibrator			

Company A site utilizes disposable 3M foam ear plugs, Model 1100[15], as shown below in Figure 15. These particular plugs have a noise reduction rating (a unit of measurement used to determine the effectiveness of hearing protection devices to decrease sound exposure within a given working environment, NRR) of 29 dB.

Figure 10 3M Foam Ear Plugs, Model 1100

4.5.1. Noise Survey Methodology

The noise survey was completed when the workers used the rad gun to remove the channel head and again when they were using the bundle puller. This survey was completed at the location of the worker for the duration of the rad gun use; typically this would be done in bursts with the rad gun. This occurred frequently over a ten hour shift.

The bundle puller ran in increments of 1 hour with 1 hour breaks in idle for a ten hour shift. The noise survey was conducted over the entire ten hour shift and logged. This data was tabulated to determine if the measures they have in place are enough to minimize noise exposure.

5. Results

The results presented in this section are based on data obtained from the gas and vapor, noise, and ergonomic assessments described in the previous section. No results are presented for

[15] 3M is a Registered Trademark of 3M Occupation Health and Environmental Safety Division, St. Paul, MN

potential exposures to NORM's because the client determined that this was not necessary. Likewise for the respiratory protective equipment, no survey was required as all the personnel working had the appropriate respiratory protective training and fit testing.

5.1. Gas and Vapor Survey Results

The gas and vapor toxicological survey was completed by Client A's operations group and the author, surveying the work area when the workers were wearing SCBA. This monitoring was performed to quantify the potential airborne contaminants that may be generated during the blinding and channel opening process. As displayed in Table 8, no detectable concentrations of flammable gases or CO were observed and the oxygen concentrations were continuously reported between 20 and 21%. However, there were detectable concentrations of H_2S during the first two hours. These data indicate that the cleaning, washing, purging, and blow drying process that was completed by Client A's Operations Group, appears to be effective in controlling potential worker exposures to H_2S during the maintenance processes; however the H_2S levels that were present in the initial hours of work warrant further investigation by Client A to determine if the cleaning, washing and purging cycle needs to lengthen.

Table 8 BW GasAlert Quattro Results

Hour	H_2S (LOD – 0.1 ppm)	LEL (LOD–0.1 %)	CO (LOD–1PPM)	O_2
1	3 ppm	<LOD	<LOD	20.5%
2	5 ppm	<LOD	<LOD	20.2%
3	<LOD	<LOD	<LOD	20.9%
4	<LOD	<LOD	<LOD	20.9%
5	<LOD	<LOD	<LOD	20.9%
6	<LOD	<LOD	<LOD	20.9%
7	<LOD	<LOD	<LOD	20.9%
8	<LOD	<LOD	<LOD	20.9%
9	<LOD	<LOD	<LOD	20.9%

10	<LOD	<LOD	<LOD	20.9%

Table 9 BW GasAlert Extreme Results

Hour	**H_2S** **(LOD – 0.1 ppm)**
1	<LOD
2	<LOD
3	<LOD
4	<LOD
5	<LOD
6	<LOD
7	<LOD
8	<LOD
9	<LOD
10	<LOD

The results from the atmospheric monitoring show that the mitigations (clean, wash, purge) put in place before the work minimized hazards that may be present. However, the Operations group put one more mitigation in place by ensuring the workers wore breathing air because there was no way to demonstrate this until the flanges were opened. These two measures, elimination via cleaning and purging the lines, and PPE effectively ensure the hazards are effectively controlled for the maintenance workers. With this hazard properly mitigated, additional potential hazards include are ergonomic stresses and noise.

5.2. Ergonomic Results

Through observation of all the workers, the REBA tool was applied with the following results.

The A score was a 4 based on a neck score of 1 (10-20 degree angle), a trunk score of 2 (0-20 degree angle), a leg score of 1 (legs straight), all combined with a force score of 2.

The B score given was an 8, based on a 3 for the upper arm being extended out, a 2 for the lower arm bent, a 1 for the wrist location and a coupling score of 1 based on time.

When charting this with the A score, this results in a 7 on Table C. The activity score for this activity adds 1 to this score, resulting in a final REBA score of 8.

As shown below in Figure 10 the final REBA score of 8 indicates high risk and calls for further investigation and engineering and/or work method changes to reduce or eliminate MSD risk.

The process that is being utilized needs to be re-evaluated and engineered to reduce the risk, something that will be explored in the recommendations section of this report.

5.3. Noise Survey Results

The sound pressure levels were surveyed for entire shifts using the noise dosimeter (A noise dosimeter is a specialized sound level meter intended specifically to measure the noise exposure of a person integrated over a period of time) to determine Company B's workforce exposure. This was done over two 10 hour shifts as the work with the rad gun took place throughout the first shift and the bundle puller was utilized for extraction on the second shift.

Results of the readings for when the rad gun was utilized are tabulated in Tables 10 and 11. The readings were taken at both A weighting and C weighting to determine which frequency was dominant. Since the readings for A weighting and C weighting were close, we conclude high frequency dominance.

The readings were taken at locations 0 meters (center of work area) to 2 meters to either side horizontally and at heights (levels of scaffold deck) of 1 meter, 2 meters and 3 meters to determine control zones for workers within the surrounding areas. These readings were taken along the horizontal axis in 3 locations at the vertical level ground level (0 meters), 1 meter, 2 meters and 4 meters. This was done as a baseline at the start of tool usage to determine the hearing protection requirements.

The readings were also taken throughout the shift, i.e. the sound level was surveyed during breaks as well. Table 10 shows the results of the exposure of those time periods.

The readings reached maximum levels of 105.7 dBA at the source and dropped to 85.4 dBA when measured at the 3 meter mark on the vertical axis.

Table 10 A Weighting Sound Level Readings

Vertical Axis	2 meters from Source (Source to East)	Source	2 meters from Source (Source to West)	Axis Average
0 meters (Source Location)	91.7	105.7	91.4	**96.3**
1 meter	89.4	97	89.2	**91.9**
2 meters	87.5	89.1	87	**87.9**
3 meters	86	86.3	85.4	**85.9**

Table 11 C Weighting Sound Level Readings

Vertical Axis	2 meters from Source (Source to East)	Source	2 meters from Source (Source to West)	Axis Average
0 meters	89.9	103.9	89.2	**94.3**
1 meter	87.8	95.5	87.4	**90.2**
2 meters	85.4	88.4	85.1	**86.3**
3 meters	84.4	84.9	83.2	**84.2**

Table 12 Time Interval Exposure

Time	Exposure	Description of Work
0700 – 0730 hrs	82 dBA	Toolbox Talk and FLRA
0730 – 0930 hrs	85 dBA	Tool Set Up
0930 – 1000 hrs	104 dBA	Rad Gun and hand tool use
1000 – 1030 hrs	80 dBA	30 Minute Lunch Break
1030 – 1330 hrs	105 dBA	Rad Gun and hand tool use
1330 – 1400 hrs	80 dBA	30 Minute Lunch Break
1400 – 1630 hrs	103 dBA	Rad Gun and hand tool use
1630 – 1700 hrs	85 dBA	Clean-up and close out meeting

Calculations were based on the American Conference of Governmental Industrial Hygienist (ACGIH) recommended values as this is what the Alberta Occupational Health and Safety Act references.

The workers shift is a 10 hour shift which means that occupational exposure limit (OEL) is actually lower, at 84.03 dB.

Limit for a given shift = $L_{\text{Exposure Time}} - 10 \log (T/8)$

Limit for a given shift = $85 - 10 \log (10/8) = 84.03$ dB

Using the average sound level readings at each axis, the allowed exposure times are (at an A weighting):

Table 13 Allowable Exposure Times

Allowable Exposure Times		
Vertical Axis	**Axis Average (dBA)**	**Allowable Exposure Time $T = 10 / 2^{(L-84.03)/3}$**
0 meters	96.3	35.2 minutes
1 meter	91.9	97.2 minutes
2 meters	87.9	245.4 minutes
3 meters	85.9	389.4 minutes

The allowable exposure times are for workers who are not protected; however, the work force in this set up was always wearing hearing protection. To determine if they were exposed, the NIOSH short calculation must be utilized.

When the workers were operating the rad gun, the noise readings were consistently in the 103-105 dBA range, which requires CSA Class A hearing protection[16] (Government of Alberta,

[16] Alberta Occupational Health and Safety – Act, Regulation and Code, Edmonton, Alberta http://humanservices.alberta.ca/working-in-alberta/53.html

2009). The workers were not exposed as they were utilizing disposable 3M Foam Ear Plugs, Model 1100[17] as shown in Table 14.

Table 14 Noise Reduction with Hearing Protection

Noise Reduction with Hearing Protection			
Vertical Axis	**Axis Average (dBA)**	**Noise Reduction From 3M Model 1100 Disposable Ear Plugs**	**NIOSH Short Calculation** estimated exposure (dBA) = workplace noise level (dBA) - (NRR - 7dB)
0 meters	96.3	29	74.3
1 meter	91.9	29	69.9
2 meters	87.9	29	65.9
3 meters	85.9	29	63.9

The time weighted average (TWA) for exposure over a shift of rad gun usage can be calculated using:

$$L_{OSHA,\,T} = 16.61 \log [(1/T) \times \Sigma (t_i \times 10^{(Li/16.61)})]$$

where t_i = duration of exposure to level L_i and T is the total sample duration

Using this formula, the TWA for the shift was 100.7 dBA, which, when using the NIOSH short calculation with the NRR from the 3M ear plugs, gives an estimated exposure of 78.7 dBA when wearing the hearing protection. The workers were protected.

The same process that was used for the rad gun was also used for the bundle puller on day 2. Results of the readings for when the bundle puller was utilized are tabulated in Tables 15, 16 and 17. The readings were also taken at both A weighting and C weighting to determine which frequency was dominant; result, higher frequency dominance.

The readings were taken at locations from right at the source to 2 meters to either side horizontally and at heights (levels of scaffold deck) of 1 meter, 2 meters and 3 meters to

[17] 3M is a Registered Trademark of 3M Occupation Health and Environmental Safety Division, St. Paul, MN

determine control zones for workers within the surrounding areas. These readings were taken along the horizontal axis in 3 spots at the vertical level ground level (0 meters), 1 meter, 2 meters and 3 meters. This was done as a baseline when the pulling began to determine the hearing protection requirements (workers began with single hearing protection).

The readings were also taken throughout the shift, i.e. the sound level was surveyed during breaks as well. Table 17 shows the results of the exposure of those time periods.

The readings reached maximum levels of 111 dBA at the source and dropped to 92.6 dBA when measured at the 3 meter mark on the vertical axis.

Table 15 A Weighting Readings for Bundle Puller

Sound Level Readings A Weighting (dBA) for Bundle Puller - Initial Usage				
Vertical Axis	**2 meters from Source (Source to East)**	**Source**	**2 meters from Source (Source to West)**	**Axis Average**
0 meters	105.1	111	104.6	**106.9**
1 meter	101.4	107.8	101.1	**103.4**
2 meters	94.8	101.6	94.2	**96.9**
3 meters	93	96.7	92.6	**94.1**

Table 16 C Weighting Readings for Bundle Puller

Sound Level Readings C Weighting (dBC) for Bundle Puller – Initial Usage				
Vertical Axis	**2 meters from Source (Source to East)**	**Source**	**2 meters from Source (Source to West)**	**Axis Average**
0 meters	101.3	108.5	101	**103.6**
1 meter	98.1	102.2	97.8	**99.4**
2 meters	94.9	97.7	94.1	**95.6**

3 meters	93.2	95.6	92.8	**93.9**

Table 17 Time Interval Exposure

Time	Exposure	Description of Work
0700 – 0730 hrs	83 dBA	Morning toolbox talk and FLRA in field
0730 – 0900 hrs	87 dBA	Tool Set Up
0900 – 1000 hrs	111 dBA	Bundle Puller Usage
1000 – 1030 hrs	82 dBA	30 Minute Lunch Break
1030 – 1130 hrs	109 dBA	Bundle Puller Usage
1130 – 1230 hrs	90 dBA	Work on Bundle Puller
1230 – 1330 hrs	110 dBA	Bundle Puller Use
1330 – 1400 hrs	81 dBA	30 Minute Lunch Break
1400 – 1530 hrs	108dBA	Bundle Puller Usage
1530 – 1630 hrs	93 dBA	Work on Bundle Puller
1630 – 1700 hrs	83 dBA	Clean-up and close out meeting

Using the average sound level readings at each axis, the allowed exposure times are (at an A weighting):

Table 18 Allowable Exposure Times

Allowable Exposure Times		
Vertical Axis	**Axis Average (dBA)**	**Allowable Exposure Time $T = 10 / 2^{(L-84.03)/3}$**
0 meters	106.9	3.04 minutes
1 meter	103.4	6.83 minutes
2 meters	96.9	30.7 minutes
3 meters	94.1	58.6 minutes

The allowable exposure times are for workers who are not protected; however, the work force in this set up was always wearing hearing protection. To determine if they were exposed, the NIOSH short calculation must be utilized.

When the workers were operating the bundle puller, the noise readings were consistently in the 108-111 dBA range, which requires CSA class A hearing protection[18] (Government of Alberta, 2009), ear combined with ear muff. The workers were exposed at the source and 1 meter as they were only utilizing disposable 3M Foam Ear Plugs, Model 1100[19] as shown in Table 19.

Table 19 Noise Reduction with Hearing Protection

Noise Reduction with Hearing Protection			
Vertical Axis	**Axis Average (dBA)**	**Noise Reduction From 3M Model 1100 Disposable Ear Plugs**	**NIOSH Short Calculation** estimated exposure (dBA) = workplace noise level (dBA) - (NRR - 7dB)
0 meters	106.9	29	84.9
1 meter	103.4	29	81.4
2 meters	96.9	29	74.9
3 meters	94.1	29	72.1

The TWA for exposure over a shift of bundle puller usage can be calculated using:

$$L_{OSHA,\,T} = 16.61 \log [(1/T) \times \Sigma (t_i \times 10^{(L_i/16.61)})]$$

where t_i = duration of exposure to level L_i and T is the total sample duration

Using this formula, the TWA for the shift was 104.1 dBA, which, when using the NIOSH short calculation with the NRR from the 3M ear plugs, gives an estimated exposure of 82.1 dBA when wearing the hearing protection. The workers were protected for the TWA but were not protected

[18] Alberta Occupational Health and Safety – Act, Regulation and Code, Edmonton, Alberta http://humanservices.alberta.ca/working-in-alberta/53.html

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for short term exposure when the bundle puller was operating; recommendations were put forward to Company A.

6. Recommendations

6.1. Gas and Vapor Monitoring

The results from the gas and vapor air monitoring revealed that H_2S levels were kept below the Alberta OEL to minimize exposure to the workers. In this respect, the decontamination process was demonstrated to be successful. Based on this data, it is recommended that the cleaning/purging process be continued in the future but further study needs to occur to determine if the process needs to be longer to completely eliminate the residual H_2S. In addition, workers should don supplied air systems for all flange breaks until further atmospheric testing has been performed to characterize potential exposures.

6.2. Naturally Occurring Radioactive Material

Client A determined that there was no possibility of NORM in this unit and therefore there was no testing conducted. The only recommendations that can be given is that Company B continues to request NORM testing and Client A will determine if required based on history in the operating unit, as they did in this case.

6.3. Respiratory Protection

The results from the atmospheric testing yielded favorable results; however, the workers still donned respiratory protective equipment. No recommendations are being made for the Company B's respiratory program except to continue training and fit testing the workers as well auditing the program as needed.

6.4. **Ergonomics**

The REBA score obtained during the ergonomics survey was an 8, which is high risk and should be investigated immediately. The weight of the tool, duration of the tool use and position of the tool are all factors Company B should consider to reduce the workers ergonomic exposure.

The recommendations to improve the ergonomics of this task are as follows:

1. Rad gun design – there are rad guns that weight significantly less and are easier to handle than the current one. By lowering the weight of the rad gun, the stress imposed on the worker would also lower. This in itself is not enough to reduce the ergonomic risk though.
2. Exposure time – the exposure time utilizing the tool needs to be lowered. To do this, the crews should switch out every 30 minutes
3. Alternate tools – the use of a de-tensioning tool that employs cells and a pump would eliminate the rad gun completely. The company does have these tools in their employ but the time to complete the job will increase.

By eliminating the use of the rad gun and reducing the exposure time, the ergonomic risk will drastically reduce to a tolerable level, a level that can be managed.

6.5. **Noise Survey**

When Company B’s workers were operating the rad gun, the noise readings were consistently in the 103-105 dBA range at the source, which requires CSA Class A hearing protection[20] (Government of Alberta, 2009). The workers were within the OH&S limits as they were utilizing disposable 3M Foam Ear Plugs, Model 1100[21].

When the workers were operating the bundle puller, the noise readings were between 108 dBA and 111 dBA at the source, which is above the Alberta OH&S recommended level for single hearing protection. Alberta Occupational Health and Safety recommends an A earplug and A or B earmuff and limited exposure when the noise readings are over 105 dBA. The workers were not wearing double hearing protection. They were advised that they need to after the readings were done. All the other measurements taken showed that single hearing protection needed to be worn, which was met as it is a working requirement within live units on this site.

From this survey, the recommendations made to the company are to establish a baseline noise level for all of their equipment and set a standard for hearing protection. This baseline should also set the criteria for distance away from the equipment in which double hearing protection is still needed as well as a time limit in which the crew can continuously run the puller. In the case of the bundle puller, double hearing protection should be worn whenever a worker is within 2 meters of the equipment; this should be marked with signage and red ribbon to deter personnel from entering the work area.

A recommendation was also put forward to Company B to go to their engineering department and determine if there is a way they can engineer out the noise or reduce the levels, via muffler or some other noise suppressing device as this bundle puller is patented by Company B.

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[20] Alberta Occupational Health and Safety – Act, Regulation and Code, Edmonton, Alberta http://humanservices.alberta.ca/working-in-alberta/53.html

[21] 3M is a Registered Trademark of 3M Occupation Health and Environmental Safety Division, St. Paul, MN

7. Conclusion

The survey results proved that Client A's procedures reduced exposure to below Alberta OEL for H_2S; however, if Client A wants to attempt to completely eliminate, they need to audit their procedures and processes to determine how to get exposure to zero. This proves that Client A is capable of completing running maintenance on their equipment as long as the company supplying the workers follows their procedures.

The results proved that Company B does have the procedures in place to prevent endangering their work force for toxicity, NORM, respiratory and noise. However, for ergonomics and noise levels greater than 105 dBA, Company B has not put procedures in place to protect their workers.

The recommendations made for ergonomics (re-designing tool or using different tool) and noise (double hearing protection, signage, baseline noise assessment on all equipment) need to be followed to ensure that the work can continue without harming the workforce.

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9. Appendix A – Advantages and Disadvantages of Various Types of Reboilers

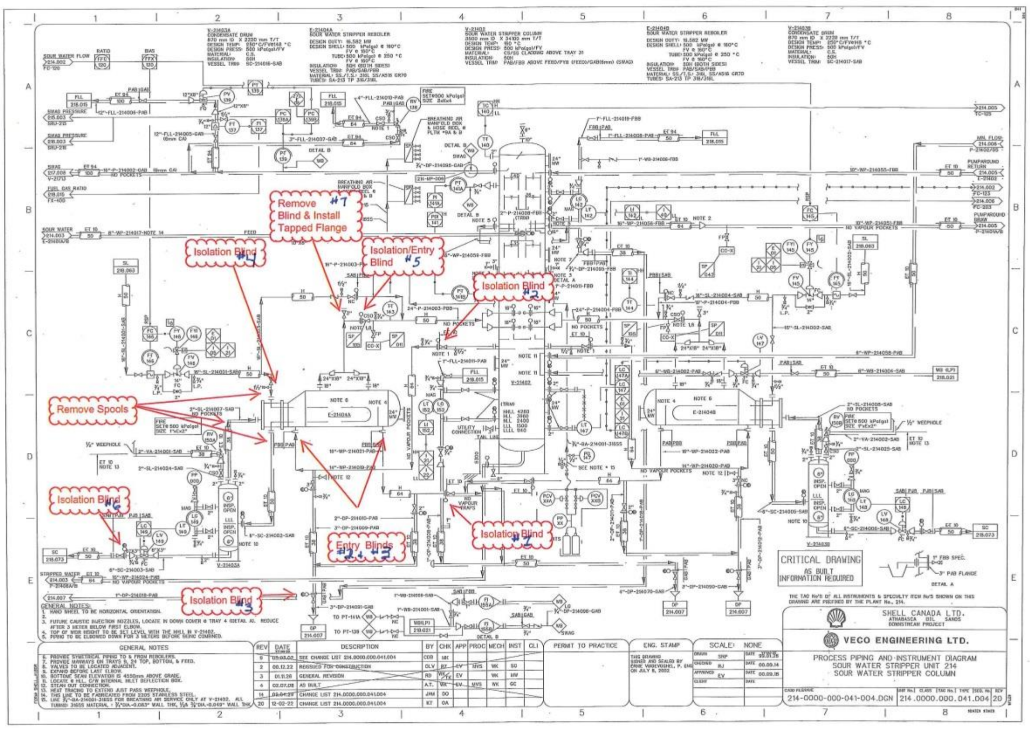
Table 1. Advantages and disadvantages of various type reboilers

Type	Advantages	Disadvantages	Remarks
Kettle reboiler	1. Most reliable in terms of operation. 2. High vaporization percentage and good vapor quality. 3. Equivalent to one theoretical stage. 4. Easy cleaning and maintenance. 5. Low circulation rate.	1. Expensive installation cost (larger shell, connection piping and level control). 2. Long residence time. 3. Not good for high-pressure boiling. 4. Lower heat flux and heat transfer rate. 5. Accumulation of heavy and polymerized substances.	1. Multiple outlets can be designed to reduce shell size. 2. Continuous blowdown can be provided to avoid accumulation of heavy and polymerized materials and, hence, reduce fouling.
Internal reboilers	1. Low installation cost. 2. No space available in vicinity of the tower. 3. For very small reboiler duty.	1. Lower heat transfer rate. 2. Process side cannot be isolated. 3. Difficult for cleaning and maintenance. 4. Tube length limited by tower diameter. 5. Cannot be counted as one theoretical stage.	Normally not recommended.
Vertical thermosyphon reboiler	1. High heat transfer rate. 2. Occupy less space. 3. Simple piping. 4. Low residence time. 5. Not easily fouled. 6. Good controllability. 7. Low installation cost for fixed tubesheet design.	1. Maximum vaporization fraction shall not exceed 30% per HTRI. 2. Limited tube length, normally not over 16 ft. 3. Not easily accessible for maintenance and repair. 4. Some designs require expansion joint on shell.	1. For critical towers, dual reboilers are normally designed with 70% capacity and can be readily isolated for repair. 2. Overall heat transfer coefficient, U_o, is in the range of 90–160 Btu/hr ft^2 °F in most HC reboilers.
Horizontal thermosyphon reboiler	1. Moderate heat transfer rate. 2. Can be designed for very large heat duty. 3. Low residence time. 4. Not easily fouled. 5. Good controllability. 6. Easy for cleaning and maintenance.	1. Extra piping required. 2. Low vaporization fraction, normally not over 35%. 3. Phase separation may occur if shellside velocity is too low. 4. Uneven flow distribution if multishell and multiinlet are designed.	1. Overall heat transfer rate, U_o, is in range of 70–100 for heavy HC and up to 150 for light HC. 2. Careful baffle design to meet ΔP requirement and to eliminate tube vibration.
Once-through natural circulation reboiler	1. As thermosyphon reboiler, has the flexibility to be either vertical or horizontal depending on tower elevation. 2. Moderate to high heat transfer rate. 3. Equivalent to one theoretical stage. 4. Low residence time. 5. Not easily fouled.	1. No control over circulation rate. 2. Danger of back-up in column. 3. Danger of excessive per-pass vaporization ratio (for vertical position).	1. Vaporization can be up to 40% of total inlet flow.
Forced circulation reboiler	1. Suitable for viscous high-fouling and solid-bearing boiling liquid. 2. Circulation rate is well controlled. 3. For very large circulation rate. 4. For very large surface area requirement. 5. Furnace reboiler. 6. To avoid phase separation. 7. Enable erosion—corrosion balance. 8. Superheating is possible.	1. Highest cost due to pump, piping and control instruments. 2. Potential leaking from pump seal. 3. Additional area for pump installation. 4. High operation cost.	Forced circulation reboiler will be considered only when kettle-type or horizontal thermosyphon reboiler cannot work.

10. Appendix B - Acute and Chronic Effects of Hydrogen Sulfide

Concentration (ppm)	Length of exposure	Effects	Source
0.0057	*Community/chroni*	*Eye and nasal symptoms, coughs, headaches and/or migraines*	*Partti-Pellinen, p.316.*
0.003 – 0.02	Immediate	Detectable odor	EPA Report 1993, p.III-5
0.01	*Community/chroni*	*Neurophysiological abnormalities*	*Legator, p.124.*
0.1 – 1	*Not reported (n.r.)*	*Abnormal balance with closed eyes, delayed verbal recall, impaired color discrimination, decreased grip strength*	*Kilburn, 1999, p.210.*
0.2	n.r.	Detectable odor	Fuller, p.940
0.250 – 0.300	Prolonged	Nuisance due to odor from prolonged exposure	Milby, p.194
1 – 5	*n.r.*	*Abnormal balance with open and closed eyes, delayed verbal recall, impaired color discrimination, decreased grip strength, abnormal simple and choice reaction time, abnormal digit symbol and trailmaking.*	*Kilburn, 1999, p.210* *EPA Report 1993, p. III-32.*
2 – 8	*Community*	*Malaise, irritability, headaches, insomnia, nausea, throat irritation, shortness of breath, eye irritation, diarrhea, and weight loss*	
10	10 minutes	Eye irritation, chemical changes in blood and muscle tissue after 10 minutes	New York State Department of rt
> 30	Prolonged	Fatigue, paralysis of olfaction from prolonged exposure	Snyder, p.200
50	n.r.	Eye and respiratory irritation	Fuller, p.940
50 – 100	Prolonged	Prolonged exposure leads to eye irritation; eye irritation (painful conjunctivitis, sensitivity to light, tearing, clouding of vision) and serious eye injury (permanent scarring of the cornea)	Milby p.194; EPA Report 1993,
150 – 200	n.r.	Olfactory nerve paralysis	EPA Report 1993, p.III-6
200	n.r.	Respiratory and other mucous membrane irritation	Snyder, p.200
250	n.r.	Damage to organs and nervous system; depression of cellular metabolism	EPA Report 1993, p.III-5
250	Prolonged	Possible pulmonary edema from prolonged exposure	Milby p.193
320 – 530	n.r.	Pulmonary edema with risk of death	Kilburn (1999), p.212
500	30 minutes	systemic symptoms after 30 minutes	Fuller, p.940
500 –1000	Immediate	Stimulation of respiratory system, leading to hyperpnoea	EPA Report 1993, p.III-5
750	Immediate	Unconsciousness, death	Fuller, p.940
1000	Immediate	Collapse, respiratory paralysis, followed by death	Fuller, p.940, EPA Report 1993 p.
750 – 1000	Immediate	Abrupt physical collapse, with possibility of recovery if exposure is terminated; if not terminated, fatal respiratory paralysis	Milby, p.192
1000 – 2000	n.r.	Immediate collapse with paralysis of respiration	Kilburn (1999), p.212

11. Appendix C Blind Points



12. Appendix D Blind List for Isolation

Page 1 of 1

Shell Scotford Upgrader Blindlist ISO__X__ENT_____

Isolation Card #1

Unit Number 214

E-21404A

Pull tube bundle for cleaning/inspection

Date__________

Tag #	Size	Blind Type	Service	Location	Normal Operating Position	Remarks	Required Maintenance Position	Maintenance Position Confirmed	Returned to Operating Position
1	16"	Spade	SSW	water outlet isolation valve	O		C		
2	14"	Spade	sour water	water inlet isolation valve	O		C		
3	3"	Spec	sour	common drain valve at grade	O		C		
4	16"	Blind Flange	LP steam	Steam inlet valve	O	Remove spool piece and install blind flange at the steam valve	C		
5	24"	Spade	steam	Vapour return valve	O	will act as both an ISO and an ENTRY blind	C		
6	6"	Spec	stm cond	condensate valve D/S of LV214149	O		C		
7	3"	Blind Flange	sour	3" top vent on vapour retun line	O	install tapped flange for 3/4 threaded connection	C	O March 17/14	

13. Appendix E Blind List For Entry

Page 1 of 1

Shell Scotford Upgrader Blindlist ISO_____ ENT__X__

Isolation Card #1________

Unit Number__214____

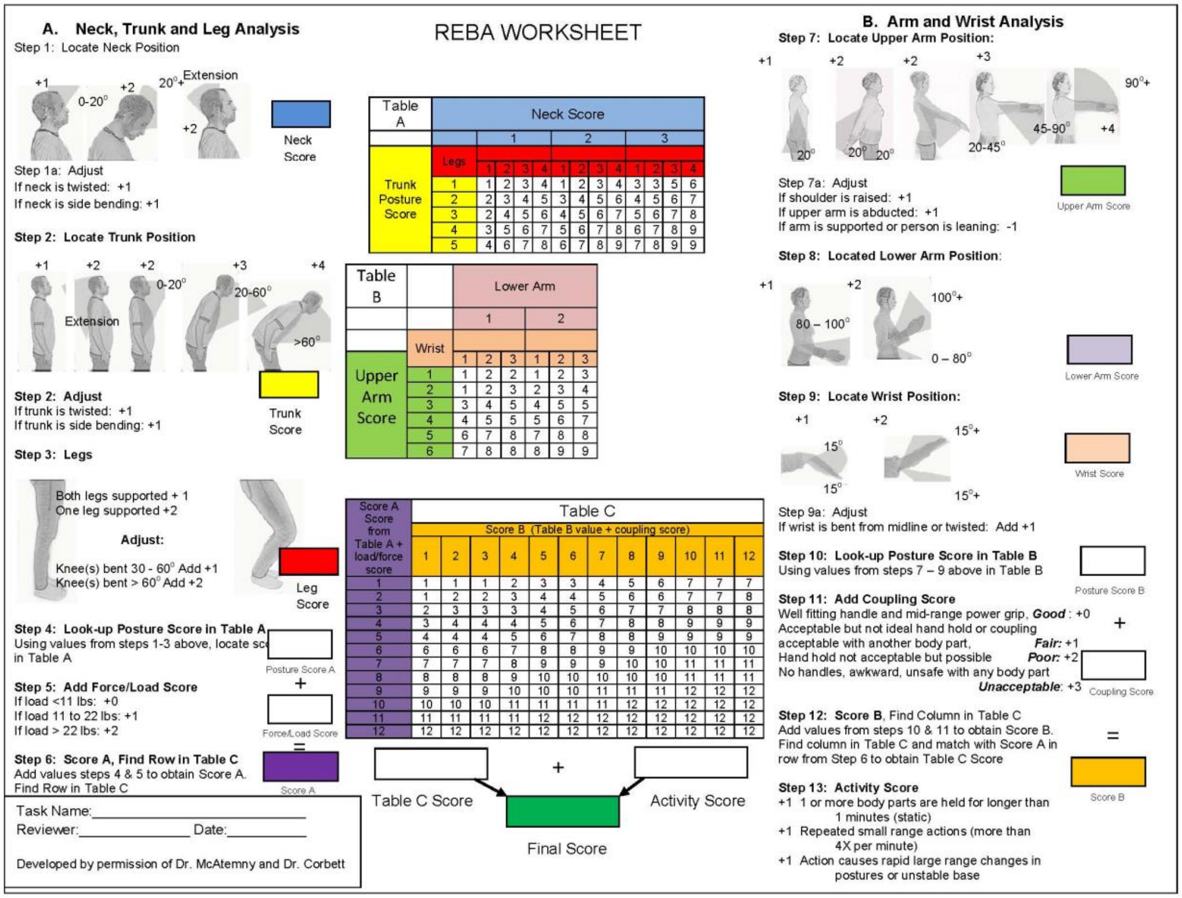
E-21404A

Pull tube bundle for cleaning/inspection

Date____________

Tag #	Size	Blind Type	Service	Location	Normal Operating Position	Remarks	Required Maintenance Position	Maintenance Position Confirmed	Returned to Operating Position
1	16"	Spade	steam	Vapour line outlet at isolation valv	O		C		
2	14"	Spade	SSW	water inlet line on underside of reboiler	O		C		
3	16"	Spade	SSW	water line outlet underside of reboiler	O	scaffold required	C		

14. Appendix F REBA Tool



REBA WORKSHEET

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 0-20° +2 20°+ Extension +2

Neck Score

Step 1a: Adjust
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position

+1 +2 Extension +2 0-20° +3 20-60° +4 >60°

Step 2: Adjust
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs

Both legs supported + 1
One leg supported +2

Adjust:

Knee(s) bent 30 - 60° Add +1
Knee(s) bent > 60° Add +2

Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above, locate score in Table A

Posture Score A

+

Step 5: Add Force/Load Score
If load <11 lbs: +0
If load 11 to 22 lbs: +1
If load > 22 lbs: +2

Force/Load Score

=

Step 6: Score A, Find Row in Table C
Add values steps 4 & 5 to obtain Score A.
Find Row in Table C

Score A

Task Name:______________________
Reviewer:______________ Date:___________

Developed by permission of Dr. McAtemny and Dr. Corbett

Table A		Neck Score											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Score A Score from Table A + load/force score	Table C: Score B (Table B value + coupling score) 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score

Final Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 20° +2 20° 20° +2 +3 20-45° 45-90° +4 90°+

Step 7a: Adjust
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Located Lower Arm Position:

+1 80 – 100° +2 100°+ 0 – 80°

Lower Arm Score

Step 9: Locate Wrist Position:

+1 15° 15° +2 15°+ 15°+

Wrist Score

Step 9a: Adjust
If wrist is bent from midline or twisted: Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7 – 9 above in Table B

Posture Score B

+

Step 11: Add Coupling Score
Well fitting handle and mid-range power grip, ***Good*** : +0
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***Fair:*** +1
Hand hold not acceptable but possible ***Poor:*** +2
No handles, awkward, unsafe with any body part ***Unacceptable***: +3

Coupling Score

=

Step 12: Score B, Find Column in Table C
Add values from steps 10 & 11 to obtain Score B.
Find column in Table C and match with Score A in row from Step 6 to obtain Table C Score

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minutes (static)
+1 Repeated small range actions (more than 4X per minute)
+1 Action causes rapid large range changes in postures or unstable base